FINAL REPORT

August 15, 2008 to January 11, 2011

Application of Pixel-cell Detector Technology for Advanced Neutron Beam Monitors

DOE-SBIR GRANT No. DE-FG02-07ER84844

Award Recipient:

ORDELA, Inc.
1009 Alvin Weinberg Drive
Oak Ridge, Tennessee 37830

Principle Investigator:
Daniel M. Kopp

Project Summary

A prototypical 2 x 4 Pixel-Cell Neutron Beam monitor was conceptualized, designed, and constructed during the Phase I project. This prototype unit was successfully tested and evaluated in a neutron beam at the High Flux Isotope Reactor (HFIR) in Oak Ridge. For the proof of principle testing, the prototypic beam monitor was connected to existing in-house data processing electronics and the performance capabilities were analyzed.

During the Phase I research effort, questions were answered about the feasibility of using the pixel-cell technology to develop a new generation of beam monitors. The prototype Pixel-Cell Beam Monitor was built and used to show that it is capable of being put in extremely high neutron flux beams and provides beam position-sensitivity in two-dimensions.

During this reporting period, ORDELA, Inc. has made significant progress toward the development of Pixel-Cell Neutron Detectors and Read-Out Systems meeting requirements of DOE supported large-scale steady-state and pulsed neutron scattering user facilities.

Based on Phase 1 studies and results of subsequent testing at ORDELA, some modifications have been made to the prototype beam monitor. Small changes to the insulation materials, feedthroughs, and sensors that were identified in testing have been implemented during this reporting period. These changes optimized the pixel-cell for regular operation in a typical neutron beam. The pixel-cell beam monitor was filled with 2691 torr of He-3/Cf4 (70/30%) counting gas mixture. The counting gas mixture has been optimized for use with cold neutrons (~ 5 Angstrom wavelength). With this mixture, the efficiency for cold neutrons is >60%.

The pixel-cell design parameters were optimized during the testing phase of the monitor. The changes were applied to the design and development of a Two-Dimensional Pixel-Cell Area Detector in Phase II development. Work was begun and completed during this effort with emphasis on creating a prototype modular pixel-cell and electronic package design that:

1) will be easily produced,
2) is scalable for larger area detectors,
3) can be built within the budget and scope of this grant award.

Within the scope of this effort the prototype Two-Dimensional Pixel-Cell Detector module was designed, fabricated, and tested.

Work was started and completed on the electronics and data processing circuits. Most of the electronics have been developed by ORDELA, Inc. under a previous Phase II DOE-SBIR project. These electronics are perfectly suited and adaptable for the evaluation proposed here. The equivalent input noise charge of the preamplifiers is <0.5 fC (rms) and the charge gain is ~33 mV per fC. These noise and gain characteristics are well suited for input stages of the proposed pixel-cell and will, therefore, be used for the evaluation phase.

The prototype detector was exposed to an intense neutron beam at the Oak Ridge Laboratories HFIR HB2D Test Beam Site. As with the prototype pixel-cell beam monitor, initial measurements were made on 1) efficiency, 2) uniformity across the detector, and 3) position resolution. These data yielded conclusive results as to the applicability of pixel-cell technology to advance neutron detector technology.

Phase II Performance Schedule - This progress report follows closely the work plan outlined in the proposal for DOE Phase II grant No. DE-PS02-08ER08-17. All phases of this work were completed within twenty-four (24) months of the grant award date. The work plan was divided into seven (7) distinct phases.

(1) Design changes and modifications to prototype Pixel-Cell Monitor. This task is was completed August 2009.

(2) Software for revision and Pixel-Cell Beam Monitor. This was completed August 2009.

(3) Interfacing with Data Acquisition System at SNS and final testing of prototype Pixel-Cell Beam Monitor at SNS reflectometer. This task was completed August 2009.

(4) Pixel-Cell Area Detector design and development and construction. This was completed June 2010.

(5) Testing of the Two-Dimensional Area Detector and interface to existing data acquisition systems. This task was completed September 2010.

(6) Testing at Reflectometer and SANS Instruments. This task was completed in December 2010.

(7) Analyzing results and writing reports. This task is completed. A detailed final report of all data and results will be issued. Publication of the results in open literature and patent applications will be considered.

Phase II Work Completed - The present development work has succeeded in producing a prototypic 8 x 8 pixel-cell detector module meeting all the requirements specified for SNS Instruments. This module is marketed as the ORDELA Model 8064N and offers significant improvements as outlined below:

1. By providing discrete, independent pixel-cell detectors for each resolution element, (a) count rates of 10E+5 neutrons per pixel (independent of adjacent pixels) are feasible regardless of detector size; (b) multiple counting of single events is intrinsically avoided because the tracks of charged particles (tritons and protons) resulting from any neutron interaction are confined to a single pixel cell; (c) the dark current and gamma-background sensitivity are intrinsically low because the probability of background radiation losing sufficient energy in any pixel cell to exceed the discriminator threshold is negligible; and (d) even if an intense reflection (>10E+7 neutrons per second per pixel) may temporarily disable or saturate a pixel cell, adjacent pixels are not affected, whereas in tubular or multiplexing detectors a whole column of pixels is disabled by a single, intense reflection.

2. The flat entrance window of the pixel-cell detectors reduces the timing jitter to <4 ns essentially independent of pixel-cell depth. Increased cell depth (~1 cm) allows to maintain good detection efficiency (~50%) for 80 meV neutrons.

3. An optimized configuration of detector modules will allow integration of a large number of these modules in a variety of sizes and shapes without tiling artifacts.

4. The amplifier-per-pixel design greatly simplifies the electronics and does not require substantial research and development efforts. A simple preamplifier and discriminator circuit is all that is needed to send the neutron data to the data processing electronics. No sophisticated decoding schemes are required.

5. The pixel-cell anodes operate at low gas multiplication (<10) to increase the durability of the detector modules when exposed to high neutron beam intensity.

Tests with the prototypic detector modules have produced results indicating that all specified parameters can be met. The initial tests with single cell detectors showed that count rates of >2 x 10E+5 neutrons per second were detected without saturation of the anode or the amplifier and discriminator channel. The results obtained from these tests led to the development of an 8 x 8 pixel-cell detector module, containing 64 independent cells of 1.0 cm x 1.0 cm x 1.0 cm deep. The anode of each cell is connected to a charge-sensitive amplifier and a remotely controlled discriminator circuit. The 64 outputs of the discriminators are connected to a multi-channel register for time stamping and counting. The time stamping interval is 100 ns. The detector volume contains 3He at ~6100 torr to reduce the timing uncertainty for individual neutrons to ~4 ns. The total processing time for each detected neutron is <500 ns.

A prototypic detector module of 64 pixel cells was instrumented and tested (figure 1). It is available for testing in a pulsed neutron source for detailed characterization and verification of the specified response.

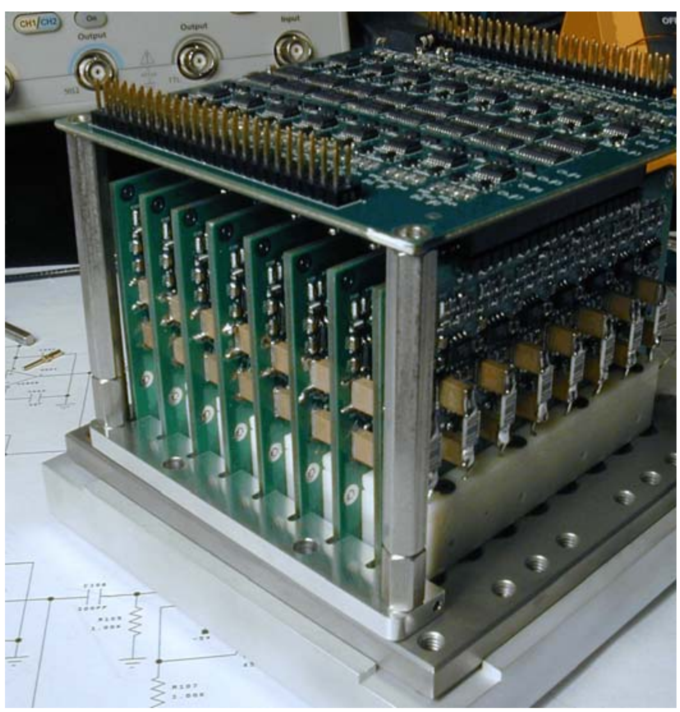

Figure 1 - ORDELA 8cm x 8cm Pixel Cell Neutron Detector

Conclusions

The development and test results have provided the required data to initiate the fabrication and commercialization of this next generation of neutron-detector systems. ORDELA, Inc. has (1) identified low-cost design and fabrication strategies, (2) developed and built pixel-cell detectors and instrumented a 64-pixel-cell detector to specifications for the Cold-Neutron Chopper Spectrometer and POWGEN instruments, (3) investigated the general characteristics of this technology, (4) studied pixel-cell configurations and arrived at an optimized modular design, and (5) evaluated fabrication costs of mass production for these configurations.

The resulting technology will enable a complete line of pixel-cell-based neutron detectors to be commercially available. ORDELA, Inc has a good track history of application of innovative technology into the marketplace. Our commercialization record reflects this.

Daniel M. Kopp
Principal Investigator